7-2012

Machinery Productivity Estimates from Seed Tenders

Robert D. Grisso
Virginia Polytechnic Institute and State University

H. Mark Hanna
Iowa State University, hmhanna@iastate.edu

Randy K. Taylor
Oklahoma State University

David H. Vaughn
Virginia Polytechnic Institute and State University

POLJOPRIVREDNA TEHNIKA
Godina XXXVII
Broj 1, jul 2012.
Strane: 81 - 91

Poljoprivredni fakultet
Institut za poljoprivrednu tehniku

UDK: 631.331

Originalni naučni rad
Original scientific paper

MACHINERY PRODUCTIVITY ESTIMATES FROM SEED TENDERS

Robert D. Grisso[1*], Mark H. Hanna[2], Randy K. Taylor[3], David H. Vaughan[1]

[1]Virginia Tech University, College of Agriculture and Life Sciences, Department of Biological Systems Engineering, Blacksburg, VA, USA
[2]Iowa State University, College of Agriculture and Life Sciences, Agricultural and Biosystems Engineering Department, Ames, IA, USA
[3]Oklahoma State University, College of Agricultural Sciences and Natural Resources, Biosystems and Agricultural Engineering Department, Stillwater, OK, USA

Abstract: Several methods and machines have been introduced during the last five years that can improve the timeliness and productivity of planting operations. Several manufacturers claim these devices can increase productivity by more than 50% over conventional methods. This paper provides insights on the improvement of corn and soybean planting systems, while using a seed tender and other similar devices. A comparison between machine operations is analyzed with the assumptions made by these claims. While the claims may be valid, farm clientele deserve to know the conditions under which these improvements can be expected. The results can assist farmers in evaluating how these purchases influence machine productivity, and how to identify potential operational areas that can improve their productivity with existing machinery systems. It also provides better estimates for parameters currently listed as ranges within the ASABE Standards.

Key words: *seed tenders, machinery management, management parameters, decision-making, machine productivity*

INTRODUCTION

Machine capacity information is crucial for machinery management decisions. Machine capacity is used to predict how equipment will perform in a farm system and determines timeliness of operation. If a series of operations contain an activity that becomes a "systems bottleneck" [1] by increasing the time to perform an individual step,

* Corresponding author. E-mail: rgrisso@vt.edu

the entire system will have lower capacity, and timely completion of a task will be affected [2]. Timeliness is defined as the "ability to perform an activity at such a time that crop return is optimized considering quantity and quality of product" [3,4].

MATERIALS AND METHODS

Machine Capacity versus Field Efficiency. Most farmers focus mainly on capacity (ha/h) of a machinery operation when discussing machinery decisions. Their interest in capacity provides a quick evaluation of the ability to complete the task. However, most farm operations usually include other unit operations that must be completed during the task. For example, during planting, operators must refill seed and agrochemical boxes or tanks as they are emptied. Or in a harvest operation, grain is moved away from the combine or forage harvester so that these units remain operational with minimal delays. In logistics terms, unit operations are usually the infrastructure that supports a desired task.

This discussion focuses on field efficiency because field efficiency addresses the impact of supporting activities during the operation. The field efficiency value evaluates the impact of machinery decisions and different operational strategies. For example, as a farmer increases the size of a planter unit by increasing the number of rows, thereby increasing the width, the theoretical field capacity increases linearly with the width. However, if the supporting unit operations, such as refilling seed hoppers, remain the same, the effective field capacity of the planter deviates further from theoretical because the same time is required to handle seed as with the smaller planter. Therefore, productivity for the larger planter does not increase linearly.

Field Efficiency Definition. According to Hunt [5], "time efficiency is a percentage reporting the ratio of the time a machine is effectively operating to the total time the machine is committed to the operation."Strict definitions are required for determining time losses associated with operation of the machine. The following list describes the time elements that involve labor, which are associated with typical field operations, and that should be included when computing the capacities or costs of machinery associated with various farm enterprises:

1. Machine preparation time at the farmstead, including removal from and preparation for storage and also shop work;
2. Travel time to and from the field;
3. Machine preparation time in the field both before and after operations, including daily servicing, preparation for towing, etc.;
4. Theoretical field time which is the time the machine is operating in the crop at an optimum travel speed and performing over its full width of action;
5. Turning time and time crossing grass waterways while machine mechanisms are operating;
6. Time to load or unload the machine's containers, if not done on-the-go;
7. Machine adjustment time, if not done on-the-go, including unplugging;
8. Maintenance time, including refueling, lubrication, chain tightening, etc., if not done on-the-go, but does not include daily servicing;

9. Repair time, which is the time spent in the field to replace or renew parts that have become inoperative; and
10. Operator's personal time.

The operator's personal time (Item 10) is a highly variable quantity and is usually unrelated to the operating efficiency of the machine. Consequently, it is often not considered as time lost and is not charged against machine operation. For similar reasons, Items 1, 2, and 3 are often excluded from consideration. The remaining elements (Items 4-9) are the items included in field efficiency.

Specifically, field efficiency [4] is the "ratio between the productivity of a machine under field conditions and the theoretical maximum productivity." Field efficiencies for specific machines can vary widely.

By definition, field efficiency requires timing of non-productive activities (lost time). According to Bainer *et al*. [6], the field efficiency can be written as:

$$e = \frac{kt_p}{t_p + t_h + t_a} \tag{1}$$

Where
e - field efficiency (decimal),
k - implement width utilization (decimal),
t_p - theoretical field time (item 4),
t_h - time loss due to interruptions that are not proportional to area,
t_a - time loss due to interruptions that tend to be proportional to area.

Von Bargen and Cunner [7] defined field efficiency as the primary activity time (item 4) divided by the sum of all field activities, shown as:

$$e = \frac{t_p}{\left\{ t_p + \sum_{i=1}^{n} t_i \right\}} \tag{2}$$

Where
t_i - other activity times

With the field efficiency established, an equation for effective field capacity can be determined:

$$C = \frac{Swe}{c} = C_T e \tag{3}$$

Where
C [$ha \cdot h^{-1}$] - effective capacity,
C_T [$ha \cdot h^{-1}$] - theoretical capacity,
S [$km \cdot h^{-1}$] - travel speed,
W [m] - rated width of implement,
C [$10\ m\text{-}km \cdot ha^{-1}$] - unit conversion constant.

Machinery performance studies have traditionally required the use of stopwatches with observations recorded on a clipboard [7-11]. Time-motion studies are tedious, time consuming, and require the researcher to be on–site during the operation. Recent research demonstrated the use of precision farming data to extract machinery performance information and field efficiencies [12-13].

Results of the analysis of machine performance studies are similar to other time-motion studies used in industrial applications, where the inefficiencies of a given process can be identified and quantified, and economic impacts can be assessed. Management strategies can be implemented to minimize inefficiencies and solutions verified. The analysis can be used to compare various machinery operation techniques and practices. Producers can also compare different methods [14] such as the time saved during a planting operation by using bulk seed versus seed in bags. During harvest, producers can assess time saved due to unloading on-the-go versus keeping the grain cart out of the field. Finally, assessment of machinery and operator costs can be estimated for each field or subsection instead of using whole farm enterprise averages.

Field efficiency of row-crop planting operations ranges from 50 to 75 percent and is typically 65 percent [4]. Taylor *et al*. [15] examined field efficiency and capacity of corn planters in northeast Kansas. They concluded that field capacity increased and field efficiency decreased as planter width increased. Since field efficiency decreases as a function of planter width, the relationship between planter width and field capacity is not 1:1. Thus, doubling planter width does not double field capacity.

Several engineering tools are effective in demonstrating the parameter impacts on machinery systems. One tool, a spreadsheet, can demonstrate how planter capacity and field efficiencies change as new devices and operational characteristics are considered. This exercise provides insights to the farm clientele concerning operational details and the impact of various planter options that can be applied to their specific operation.

The results detail the calculations and assumptions made by advertisers and sale representatives. Other questions considered are:

- How large are the individual seed hoppers, and how many times daily do they require filling?
- Are individual hoppers being filled with an auger from a mini-bulk seed supply?
- Or hand handling with bags?
- How do these units influence travel speeds, road transport, field compaction, and turning time?
- Are these devices cost effective?

General Machinery Management Models. Farm managers, consultants, and others working with machinery management data use capacity information to estimate costs, and select machinery to complete field operations within the time available. General machinery management models have been used to select machinery and evaluate the economics and performance of farm systems [16-18]. Timeliness costs have been shown to be an influential input into the machinery selection process [2, 19-23]. Computer models have been developed to aid the selection of optimal machinery systems for farms. The major model types include static machinery selection algorithms [20-21, 24] and dynamic simulation models [18, 25-27]. In each of these models, the number of days suitable for fieldwork is an important component in the selection and analysis of machinery systems. In order to predict the amount of work that can be accomplished, the time available within the optimal period for the required operation must be known. Most of these models assume that the field efficiency is constant no matter the size (capacity) of the equipment.

RESULTS AND DISCUSSION

Farmers have found that one of the most time-sensitive operations on the farm is planting. This finding has increased their interest in reducing the planting window to gain the advantages of early planting (without frost damages) such as better canopy closure and increased weed control, thereby resulting in increased yields. The farmer's desire to increase planter capacity has increased due to the advantages of the planter system combined with the pressure of off-farm employment, reduced labor force, increased farm size, and time commitments with other farm enterprises.

Manufacturers have complied with farmers' wishes by increasing operational planter widths and developing supporting units such as seed tenders. Seed tenders typically handle bulk seed that are carried in tanks or containers along with the planter, and then convey seed to the planter boxes during refill. In this context the tender is an on-board central seed hopper device rather than a separate tender vehicle frequently associated with nutrient or pesticide application. Various devices offer automatic refill, conveyance systems, or positioning for multiple box refills.

Several manufacturers claim seed tenders can increase planting productivity by more than 50% over conventional methods. The objective of this paper is to provide a discussion and insights on the improvement of corn and soybean planting systems while using a seed tender device with central hopper. A comparison between machine operations is analyzed using assumptions made by these claims. While the claims may be valid, farm clientele desire to know the conditions under which these improvements can be expected.

Fig. 1 and 2 show manufacturers' claims for an 18.3-m planter unit for seeding corn and soybeans, respectively. The estimated improvement from using the seed tender for the corn plant operation was 12.8% while the estimated improvement for the soybean plant operation was 52%. The only differences in the comparison are the handling of seed by hand or the use of tender device to automatically refill the planter boxes and the seeding rate differences between corn and soybean.

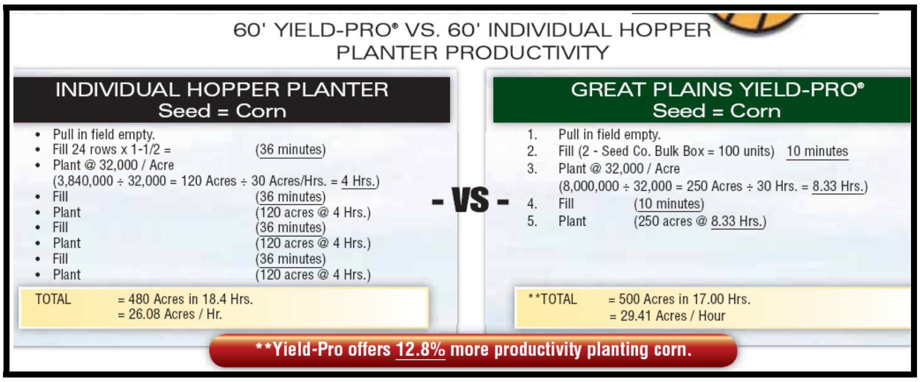

Figure 1. Manufacturing advertising claim for the improved productivity of corn planting

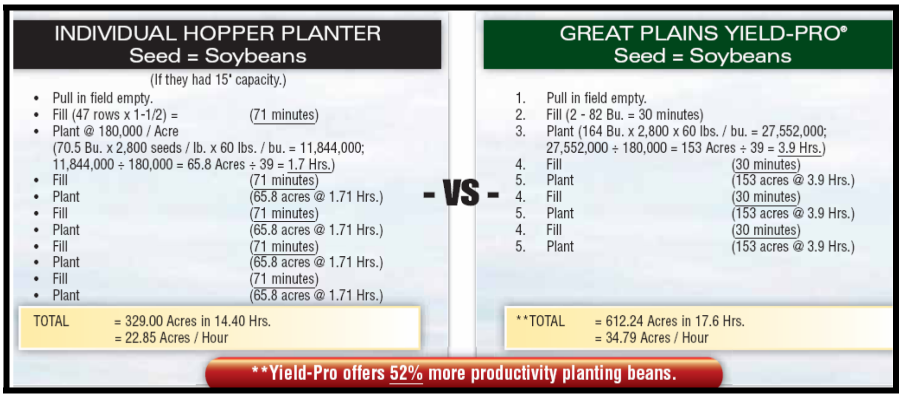

Figure 2. Manufacturing advertising claim for the improved productivity of soybean planting

<u>*Review of Claims.*</u> First, to gain insights into the manufacturer's estimates, the theoretical capacity (CT) of the planter units was computed. For corn planting, the 24-row machine width of 18.3 m (76.2 cm row spacing) with a travel speed of 8 km·h^{-1} results in a theoretical capacity of 14.7 ha·h^{-1}. The soybean planter was assumed to have the same width resulting in 47 rows at a 38.1cm row spacing with an operational speed of 10.5 km·h^{-1}, giving a theoretical capacity of 19.1 ha·h^{-1}. With these estimates, the field efficiency of the corn planting operation with handling seed bag and seed tenders is 72 and 81%, respectively. For soybean planting, the field efficiency for these same two systems is estimated to be 48 and 73.6%, respectively. These computed field efficiencies are close to the estimates projected by the ASABE Standards [4]. The soybean planting efficiency using the conventional method is below the lower limit of the ASABE Standards [4].

The individual components of these efficiency differences can now be examined. It is estimated that during corn and soybean planting, 17.5% of the time is used for all other support items such as turns at the end of rows, maintenance, etc. Thus, the remainder, 11 and 2% of the planting time, is estimated to be spent refilling the hopper by hand and using the tender, respectively. During soybean planting, refilling soybean hoppers accounts for 34 and 9% of the planting time spent for refilling the hopper by hand and by tender, respectively.

The manufacturer estimated that refilling hoppers by hand using corn seed bags would take 36 min to refill all 24 units, or 1.5 min·hopper^{-1}, which is a reasonable estimate for handling corn seed bags. This same estimate was used for a narrow row soybean planter having 47 row units or a total refill time of 71 min. While the refill rate is an estimated value it might be more accurate to base the refill rate on the mass handled instead of the row unit. Grisso *et al*. [28] estimated that the transfer time for a mechanical system at 195 kg·min^{-1} and 0.5 min to position the device over the row unit. Using these estimates the handling of seed would be 0.73 and 0.71 min·hopper^{-1} for corn and soybean, respectively. These values are about half of the estimated rate.

In these examples, the most dramatic impact occurs during the soybean planting operation; considering the seed volume and the number of row units to service, this result seems reasonable. Thus, the addition of a tender unit for corn planting would probably not result in the large improvements of productivity seen with the soybean planting operation.

Planter Size. These estimates (i.e., assuming 1.5 min·hopper^{-1} for filling individual seed hoppers and the total time specified by the manufacturer for filling the tender, seed population) were compared for several planter sizes (24-, 12-, and 6-row units with 76 cm rows) to estimate the impact of the seed tenders. The field efficiency for these three sizes of planters is shown in Fig. 3. There is less improvement in productivity from using a seed tender with planters having smaller widths. However, even with the 12-row unit, significant improvements result while sowing soybeans. Individual farmers should evaluate whether the increased productivity would warrant the additional cost of the tender unit for their planting operation. These impacts on planter capacity can be seen in Fig. 4.

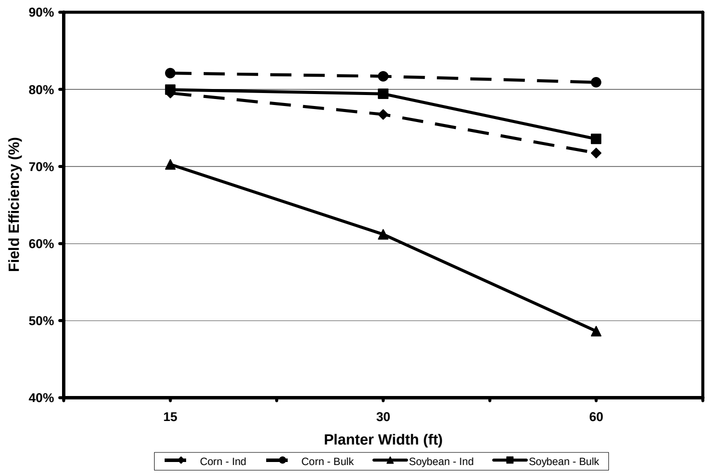

Figure 3. The field efficiency analysis of the bulk tender compared with individuals handling seed bags as a function of planter width

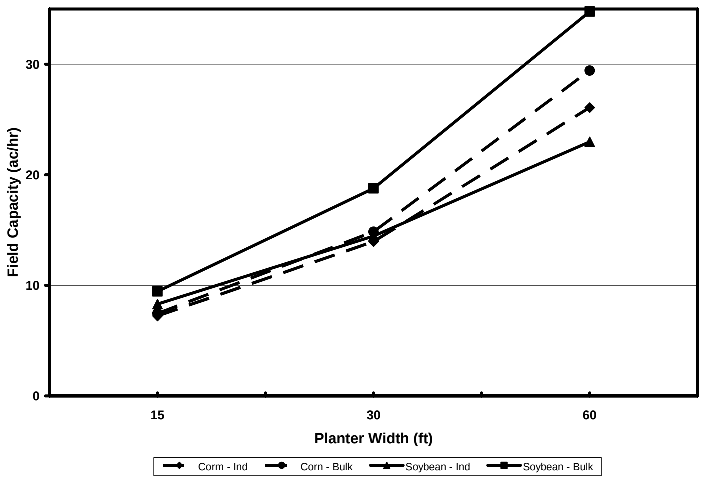

Figure 4. The effective field capacity of the bulk tender compared with individuals handling seed bags as a function of planter width

Seed Rate. The major difference in productivity increase between corn and soybean operations was the impact of seed rate and the accompanying frequency required to refill and handle the seed. The manufacturer's example uses a seeding rate of 13,000 seeds·ha^{-1} for corn and 73,000 seeds·ha^{-1} for soybeans. As a comparison, the soybean operation was evaluated over a seeding rate range from 20,200 to 85,000 seeds·ha^{-1} for different seeder widths. The estimates were based only on the changes required to handle seeds at refilling. Fig. 5 shows the impact of soybean seeding rate and the corresponding productivity improvement of using a seed tender. Smaller planters have little productivity gains from the seed tenders, but even at low seeding rates for soybeans, the productivity increases for an 18.3 m planter, exceeding 20%.

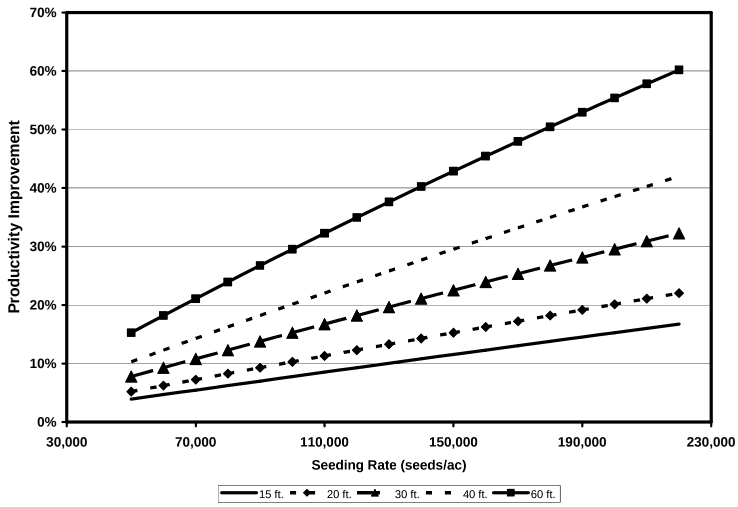

Figure 5. The productivity improvement of seeding soybeans with a bulk tender compared with individuals handling seed bags as a function of planter width and seeding rate

Economic Impact. The economic impact can be viewed in two primary ways. The first way is timeliness cost. "Does the loss of productivity during planting result in a decrease in yield at the end of the season?" Answering this question relates to the crop and variety impact on the growing degree-days and seasonal influence for untimely planting. Since this estimate is based on calendar days, timely completion can be computed. The other evaluation method determines whether the improved productivity from the seed tender meets the operator's criteria. For example, suppose the cost of investing in a larger 48 row (18.3 m) unit rather than replacing an existing 24 row (9.1 m) soybean planter was \$25·ha^{-1} and the potential gain in machine field capacity was projected to be 6.9 ha·h^{-1}. The impact for a farm operation having over 405 ha results in completion in 60 h quicker than the smaller planter or a Return on Investment (ROI) of \$167·h^{-1}. If the larger planter was unable to capture the full potential capacity and was reduced by 50% due to efficiency losses, the resulting capacity gain would be only 3.9 ha·h^{-1}. Then the difference would mean that the larger planter would only gain 30 hours over the smaller planter. If the cost of owning and operating the tender offsets this value, then the tender should be purchased and implemented during soybean planting. However, with the corn example, if the addition of a tender cost $25·ha^{-1} but the capacity lost was only 1.2 ha·h^{-1} then the small loss may not justify the investment of the seed tender.

Implications of Supporting Units. There are similar farm operations that have the characteristic that as their capacity is increased the supporting activities become more critical in maintaining high field efficiency. Examples include: forage chopper vs. truck to haul away the chopped forage; combine vs. grain cart/truck or on-the-go unload; biomass harvest vs. logistics to biorefinery; spray applicator vs. nurse truck; nitrogen applicator vs. nurse tank; and grain dryer vs. safe storage. Equation 2 shows that, when the supporting activities/operations (t_i) become more than 25% of the productivity time (t_p) then productivity suffers. In the case of the soybean planting operation, the 48-row planter showed a field efficiency drop below 50% and that 50% of the time while in the field other activities instead of planting were being done. To maintain field capacity the supporting activities cannot take longer than 15 minutes during an hour of field operation.

As an estimate, if the potential capacity is doubled (by doubling the operating width) while the supporting activities remain unchanged, then the supporting activities increase from 25% to 50% and loss of productivity is dramatic. This result requires the farmer to understand and be able to compute the time required for these supporting activities, and that he has a good understanding of how conditions will change them.

Other implications of using seed tenders include the following: investment in more machinery; possibility of increased soil compaction as the heavier machine traverses the field; and maintenance and repair might increase above simpler individual hoppers. An operator could preload the tender but that increases over-the-road weight and raises concerns of safety issues such as equipment braking and steering stability.

CONCLUSIONS

This paper validates the claims for a seed tender. Implications also show that no supporting activities can take more than 25% of the productivity time, or a drop in field capacity occurs. Challenges on justifying additional economic investment into improving productivity is based on the need for the additional capacity and the cost of owning and operating a seed tender.

BIBLIOGRAPHY

[1] Buckmaster, D.R., Hilton, J.W. 2003. Computerized cycle analysis of harvest, transport, and unload systems. *Proceedings of the International Conference on Crop Harvesting and Processing*, 9-11 February 2003 (Louisville, Kentucky USA) Publication Date 9 February 2003. ASAE Publication Number 701P1103e. St. Joseph, Mich.: ASAE

[2] Rotz, C.A., Harrigan, T.M. 2005. Predicting suitable days for field machinery operations in a whole farm simulation. *Applied Eng. Agric.* 21(4):563-571.

[3] ASABE Standards. 2006. ASAE D497.5 FEB 2006, Agricultural machinery management data. *St. Joseph, Mich.: ASABE*

[4] ASABE Standards. 2005 ASAE S495.1 NOV 2005, Uniform terminology for agricultural machinery management. *St. Joseph, Mich.: ASABE*

[5] Hunt, D. 1995. Farm Power and Machinery Management, *9th Ed. Ames*, Iowa: Iowa State University Press

[6] Bainer, R., Kepner, R.A., Barger, E.L. 1955. Principles of Farm Machinery, *1st Ed. New York*: John Wiley and Sons, Inc.

[7] Von Bargen, K., Cunney M.B. 1974. Activity ratio for farm machinery operations analysis. *Transactions of the ASAE* 17(2):225–227.

[8] Renoll, E.S. 1965. Row-crop machine capacity in terraced fields. *Highlights of Agr. Res., Auburn Univ*., Ala. Agr. Exp. Station. 12:(Summer)

[9] Renoll, E.S. 1970. Using operation analysis to improve row-crop machinery efficiency. *Highlights of Agr. Res., Auburn Univ*., Ala. Agr. Exp. Station. Circular 180

[10] Renoll, E.S. 1972. Concept for predicting capacity of row-crop machines. *Transactions of the ASAE* 15(5):1025-1030.

[11] Renoll, E.S. 1981. Predicting machine field capacity for specific field and operating conditions. *Transactions of the ASAE* 24(1):45-47.

[12] Grisso, R.D., Jasa, P.J., Rolofson, D.E. 2002. Analysis of traffic patterns and yield monitor data for field efficiency determination. *Applied Eng. Agric.* 18(2):171-178.

[13] Taylor, R. K., Schrock, M. D., Staggenborg, S.A. 2002. Extracting machinery management information from GPS data. *ASAE Paper No. 021008*. St. Joseph, Mich.: ASAE

[14] Reichenberger, L. 2001. Digging more data from precision farming; computerized field maps may also help manage machinery. *Successful Farming* 99(2):1-2

[15] Taylor, R.K., Schrock, M.D., Staggenborg, S.A. 2001. Using GPS technology to assist machinery management decisions. *ASAE Meeting Paper No. MC01-204*. St. Joseph, Mich.: ASAE

[16] Hunt, D. R. 1967. A FORTRAN program for selecting farm equipment. *Agric. Eng.* 48(6):332-335.

[17] Kjelgaard, W.L., Wu, Z. 1983. Micro-computer program for field machinery management. *ASAE Paper No. 831536*. St. Joseph, Mich.: ASAE

[18] Rotz, C.A., Corson, M.S., Coiner, C.U. 2007. Integrated Farm System Model, Reference Manual, Version 2.1. Available at: http://www.ars.usda.gov/SP2UserFiles/Place/19020000/ifsmreference.pdf [Accessed 18 Mar 2008]

[19] Harrigan, T.M. 2003. Time-motion analysis of corn silage harvest systems. *Applied Eng. Agric.* 19(4): 389-395.

[20] Kjelgaard, W.L.K., Persson, S.P., Beppler, D.C., Wu, Z. 1985. Simulation of alternative cropping patterns and field machinery systems. *ASAE Paper No. 85-1525*. St. Joseph, Mich.: ASAE

[21] Siemens, J., Hamburg, K., Tyrrell, T. 1990. A farm machinery selection and management program. *J. of Production Agric.* 3(2):212-219.

[22] Whitson, R.E., Kay, R.D., LePori, W.A., Rister, E.M. 1981. Machinery and crop selection with weather risk. *Transactions of the ASAE* 24(2):288-292, 295.

[23] Edwards, W., Boehlje, M. 1980. Machinery selection considering timeliness losses. *Transactions of the ASAE* 23(4):810-815, 821.

[24] Kline, D.E., McCarl, B.A.1987. Farm-level machinery management using intelligent decision support system. *ASAE Paper No. 87-1046*. St. Joseph, Mich.: ASAE

[25] Kotzabassis, C., Stout, B.H., Whittaker, A.D. 1989. A Prolog tractor implement matching expert system. *ASAE Paper No. 89-7080*. St. Joseph, Mich.: ASAE

[26] Lal, H., Jones, J.W., Peart, R.M., Shoup, W.D. 1992. FARMSYS a whole-farm machinery management decision support system. *Agricultural Systems* 38(3):257-273.

[27] Harrigan, T.M., Bickert, W.G., Rotz, C.A. 1996. Simulation of dairy manure management and cropping systems. *Applied Eng. Agric.* 12(5):563-574.

[28] Grisso, R.D., Cundiff, J.S., Vaughan, D.H. 2007. Investigating machinery management parameters with computer tools. *ASABE Paper and Presentation No. 071030*. St. Joseph, Mich.: ASABE

PROCENE PRODUKTIVNOSTI MAŠINA SA UPOTREBOM POKRETNIH REZERVOARA ZA TRANSPORT I PUNJENJE SEMENA

Robert D. Grisso[1], Mark H. Hanna[2], Randy K. Taylor[3], David H. Vaughan[1]

[1] Tehnički Univerzitet Virdžinije, Fakultet za poljoprivredu i prirodne nauke, Institut za inženjering bioloških sistema, Blacksburg, VA, SAD
[2] Državni Univerzitet Ajove, Fakultet za poljoprivredu i prirodne nauke, Institut za inženjering poljoprivrede i biosistema, Ames, IA, SAD
[3] Državni Univerzitet Oklahome, Fakultet za poljoprivredne nauke i prirodne resurse, Institut za inženjering biosistema i poljoprivrede, Stillwater, OK, SAD

Sažetak: Tokom prethodnih pet godina predstavljeno je više metoda i mašina koje mogu da unaprede kvalitet i učinak setvenih radova. Proizvođači tvrde da ovi uređaji mogu da povećaju produktivnost za više od 50%, u odnosu na konvencionalne metode. U ovom radu su predstavljene analize poboljšanja sistema za setvu kukuruza i soje, uz primenu pokretnog rezervoara za transport i punjenje semena i drugih sličnih sredstava. Poređenje rada pojedinih mašina analizirano je u odnosu na navedene tvrdnje. Ukoliko su ove tvrdnje tačne, farmeri zaslužuju da znaju uslove pod kojima se navedena poboljšanja mogu očekivati. Rezultati mogu da pomognu farmerima da procene kako bi nabavka ovih uređaja uticala na radni učinak mašine i kako da prepoznaju operacije čija efikasnost može da se poboljša postojećim mašinama. Takođe, ovim su date bolje procene parametara koji su navedeni u preporučenim opsezima u ASABE Standardima.

Ključne reči: *rezervoari za seme, menadžment mašina, parametri menadžmenta, donošenje odluka, produktivnost mašina*

Datum prijema rukopisa: *Paper submitted:*	21.06.2012.
Datum prijema rukopisa sa ispravkama: *Paper revised:*	25.06.2012.
Datum prihvatanja rada: *Paper accepted:*	01.07.2012.